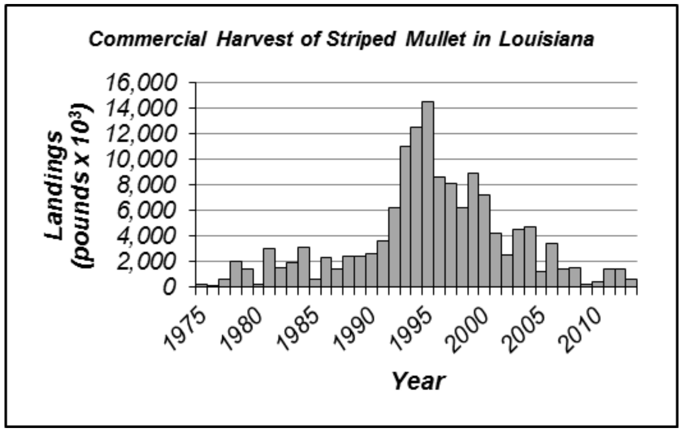
Update Assessment of Striped Mullet *Mugil cephalus* in Louisiana Waters 2015 Report

Executive Summary

Commercial landings of striped mullet *Mugil cephalus* in Louisiana have significantly decreased in the last 20 years, with the highest harvest observed in 1995. The passages of Hurricanes Katrina and Rita caused substantial reduction in the directed effort of the commercial fleet when compared to previous years. Since 2007, annual harvest has remained below two-million pounds, with extremely low landings in 2009 and 2010. Since 2010, landings have increased, but remain at historically low levels. The marked decline in commercial landings since 2000 can be attributed to impacts from several hurricanes, increases in operating costs, and decreases in the demand and price of roe.



A statistical catch at age model is used in this assessment to describe the dynamics of the Louisiana striped mullet stock (1996-2013). This model uses a maximum likelihood fitting criterion to project population size from abundance estimates in the initial year and recruitment estimates in subsequent years. Fishing mortality is estimated as year and age-specific components. Landings are taken from the Louisiana Department of Wildlife and Fisheries (LDWF) Trip Ticket Program and National Marine Fisheries Service commercial statistical records. An index of abundance is developed from the LDWF fishery-independent marine gillnet survey. Age composition of fishery and survey catches are estimated with age-length keys developed from samples directly from the fishery and a von Bertalanffy growth function.

The conservation threshold established by the Louisiana Legislature for striped mullet is a 30% spawning potential ratio. Based on results of this assessment, the Louisiana striped mullet stock is currently neither overfished or experiencing overfishing. The current spawning potential ratio estimate is 68%.

Summary of Changes from 2014 Assessment

Assessment model inputs have been updated through 2013. No changes have been made to the assessment model itself. A correction was made, however, in the fork length- total length conversions in this assessment.

Update Assessment of Striped Mullet *Mugil cephalus* in Louisiana Waters
2015 Report

Joe West
Office of Fisheries
Louisiana Department of Wildlife and Fisheries

Joseph E. Powers
School of Coast and Environment
Department of Oceanography and Coastal Sciences
Louisiana State University

Table of Contents

1. Introduction

A statistical catch-at-age model is used in this assessment to describe the dynamics of the Louisiana (LA) striped mullet *Mugil cephalus* (SM) stock. The assessment model forward projects annual abundance at age from estimates of abundance in the initial year of the time-series and recruitment estimates in subsequent years. The model is fit to the data with a maximum likelihood fitting criterion. Minimum data requirements are fishery catch-at-age and an index of abundance (IOA). Landings values are taken from the Louisiana Department of Wildlife and Fisheries (LDWF) Trip Ticket Program and the National Marine Fisheries Service (NMFS) commercial statistical records. An IOA is developed from the LDWF experimental marine gillnet survey. Age composition of fishery catches are estimated with age-length keys derived from samples directly of the fishery (2002-2013) and a von Bertalanffy growth function (1981-2001).

1.1 Fishery Regulations

The LA SM fishery is governed by the Louisiana State Legislature, the Wildlife and Fisheries Commission and the LDWF. Louisiana commercial and recreational SM fishery regulations were reviewed in the prior assessment report (West *et al.* 2014); full descriptions of historical regulations can be found in Mapes *et al*. (2001) and GSMFC (1995).

1.2 Trends in Harvest

Time-series of commercial and recreational SM landings in the Gulf of Mexico are presented (Table 1, Figures 1 and 2). Trends in harvest were reviewed in the prior assessment report (West *et al.* 2014).

2. Data Sources

2.1 Fishery Independent

The LDWF fishery-independent marine gillnet survey is used in this assessment to develop an index of abundance for use in ASAP. Below is a brief description of this surveys methodology. Complete details can be found in LDWF (2002).

For sampling purposes, coastal Louisiana is currently divided into five LDWF coastal study areas (CSAs). The definitions of those CSAs are different from that found in the 2002 field procedures manual (LDWF 2002). Current CSA definitions are as follows: CSA 1 – Mississippi State line to South Pass of the Mississippi River (Pontchartrain Basin); CSA 3 – South Pass of the Mississippi River to Bayou Lafourche (Barataria Basin); CSA 5 – Bayou Lafourche to eastern shore of Atchafalaya Bay (Terrebonne Basin); CSA 6 – Atchafalaya Bay to western shore of Vermillion Bay (Vermillion/Teche/Atchafalaya Basins); CSA 7 – western shore of Vermillion Bay to Texas State line (Mermentau/Calcasieu/Sabine Basins). The LDWF Marine Fisheries Section conducts routine standardized sampling within each CSA as part of a long-term comprehensive monitoring program to collect life-history information and measure relative abundance/size distributions of recreationally and commercially important species. These include the experimental marine gillnet, trammel net, and beach seine surveys.

In this assessment, only the experimental marine gillnet survey is used. This survey is conducted with standardized design. Hydrological and climatological measurements are taken with each biological sample, including water temperature, turbidity, conductivity and salinity. Survey gear is a 750' monofilament gillnet comprised of five 150-foot panels of 1.0, 1.25, 1.5, 1.75, and 2.0 inch bar meshes. Samples are taken by 'striking' the net; where the net is set either parallel to the shore (or reef) or set in a crescent-shape. The vessel is then maneuvered both inside and outside of the net in gradually tightening circles a minimum of three times to force fish into the net. All captured SM are enumerated and a maximum of 30 randomly selected SM per mesh panel are collected for length measurements, gender determination, and maturity information. When more than 30 SM are captured per mesh panel, catch-at-size is derived as the product of total catch and proportional subsample-at-size.

2.2 Fishery Dependent

Commercial

Commercial SM landings are taken from NMFS commercial statistical records (NMFS 2014a) and the LDWF Trip Ticket Program (Figure 1). Annual size composition of commercial catches (Table 2) are derived from the Trip Interview Program (TIPS; 1996-2001), the Fishery Information Network (FIN; 2007-2013), and by combination of data collection programs (TIPS+FIN; 2002-2006). Ages of commercial SM landings are derived from otoliths collected from LDWF sampling effort (see *Catch at Age Estimation*).

Recreational

As in prior assessments, the effects of recreational harvest on the stock were not considered. The MRFSS/MRIP harvest data (Type A+B1 only) indicates that LA recreational harvest is minimal relative to commercial harvest (Table 1; NMFS 2014b). Furthermore, only limited recreational size composition information is available from MRFSS/MRIP. The size information that is available indicates most of the recreational harvest is taken at sizes (age-0) prior to entering the commercial fishery (age-1+).

3. Life History Information

3.1 Unit Stock Definition

Striped mullet are a catadromous schooling fish common in warm, temperate coastal waters throughout the world. They are ubiquitous in the Gulf of Mexico (GOM) and can be found along extreme salinity gradients, from fresh to hyper-saline. Little or no genetic sub-structuring has been documented for GOM striped mullet. Thompson *et al.* (1991) found no differences in enzyme polymorphisms in striped mullet collected from various locations across Louisiana, or between those areas and mullet collected from the Pascagoula River, Mississippi, Mobile Bay, Alabama, and Charleston Bay (South Carolina). Campton and Mahmoudi (1991) also found little evidence for genetic sub-structuring of striped mullet populations between the Atlantic and GOM coasts of Florida. For the purpose of this assessment, the unit stock is defined as those female SM occurring in LA waters. This approach is consistent with the current statewide management strategy.

3.2 Morphometrics

Weight-length regressions for LA SM were developed by Thompson *et al.* (1991). Regression equation slopes comparing males and females were not significantly different. For the purpose of this assessment, the non-sex-specific formulation is used with weight calculated from size as:

$$W = 2.1\times10^{-5}(FL)^{2.93} \quad [1]$$

where W is total weight in grams and FL is fork length in mm. Fish with only FL measurements available are converted to TL using the relationship provided by Thompson *et al*. (1991) where:

$$TL = 1.13\times(FL) - 3.40 \quad [2]$$

3.3 Growth

Von Bertalanffy growth functions for female LA SM collected from fishery-independent data sources were developed by Thompson *et al.* (1991) with size-at-age calculated from:

$$FL_a = 471.70\times(1 - e^{-0.28(a-0.03)}) \quad [3]$$

where FL_a is FL-at-age in mm and years.

3.4 Sex Ratio

The probability of being female at a specific size is estimated with a logistic function developed in the previous assessment (West *et al.* 2014) as:

$$P_{fem,l} = \frac{1}{\left[1+e^{[-0.24(TL-10.04]}\right]} \quad [4]$$

where $P_{fem,l}$ is the estimated proportion of females in 1 inch TL intervals. The minimum sex ratio-at-size is assumed as 50:50.

3.5 Fecundity/Maturity

Per capita fecundity functions for LA SM were developed by Thompson *et al*. (1991) with fecundity-at-size computed as:

$$f_l = 5.6\times10^{-3}(FL)^{3.18} \quad [5]$$

Where f_l is the average fecundity of a size l female in FL. Fecundity-at-age f_a is then computed by substituting equation [5] into equation [3]. Female SM maturity is assumed knife-edged at age-2.

3.6 Natural Mortality

Striped mullet can live to at least ten years of age (Thompson *et al.* 1991). For purposes of this assessment, a value of constant M is assumed (0.3), but is allowed to vary with weight-at-age to calculate a declining natural mortality rate with age. This value of M is consistent with a stock where approximately 1.5% of the stock remains alive to 10 years of age (Hewitt and Hoenig 2005). Following SEDAR 12 (SEDAR 2006), the estimate is rescaled where the average mortality rate over ages vulnerable to the fishery is equivalent to the constant rate over ages as:

$$M_a = M\frac{nL(a)}{\sum_{a_c}^{a_{max}} L(a)} \quad [6]$$

where M is a constant natural mortality rate over exploitable ages a, a_{max} is the oldest age-class, a_c is the first fully-exploited age-class, n is the number of exploitable ages, and $L(a)$ is the Lorenzen curve as a function of age. The Lorenzen curve as a function of age is calculated from:

$$L(a) = W_a^{-0.288} \quad [7]$$

where -0.288 is the allometric exponent estimated for natural ecosystems (Lorenzen 1996) and W_a is weight-at-age.

3.7 Relative Productivity / Resilience

The key parameter in age-structured population dynamics models is the steepness parameter (h) of the stock-recruitment relationship. Steepness is defined as the ratio of recruitment levels when the spawning stock is reduced to 20% of its unexploited level relative to the unexploited level and determines the degree of compensation in the population (Mace and Doonan 1988). Populations with higher steepness values are more resilient to perturbation and if the spawning stock is reduced to levels where recruitment is impaired are more likely to recover sooner once overfishing has ended. Generally, this parameter is difficult to estimate due to a lack of contrast in spawning stock size (*i.e.,* data not available at both high and low levels of stock size) and is typically fixed or constrained during the model fitting process. Estimates of steepness are not available for GOM striped mullet.

Productivity is a function of fecundity, growth rates, natural mortality, age of maturity, and longevity and can be a reasonable proxy for resilience. We characterize the relative productivity of LA SM based on life-history characteristics, following SEDAR 9, with a classification scheme developed at the FAO second technical consultation on the suitability of the CITES criteria for listing commercially-exploited aquatic species (FAO 2001; Table 4). Each life history characteristic (von Bertalanffy growth rate, age at maturity, longevity, and natural mortality rate) is assigned a rank (low=1, medium=2, and high=3) and then averaged to compute an overall productivity score. In this case, the overall productivity score is 2.5 for LA striped mullet indicating medium to high productivity and resilience.

4. Abundance Index Development

An index of abundance (IOA) was developed from the LDWF FI marine gillnet survey for use in this assessment. Only those CSAs, months, and mesh panels with ≥5% positive samples are included in index development. Stations not sampled regularly through time are also excluded. For purposes of this assessment, catch-per-unit effort (CPUE) is defined as the number of female SM caught per gillnet sample. The number of female mullet caught per gillnet sample is calculated from each samples catch at size and equation [4]. To reduce unexplained variability in catch rates unrelated to changes in abundance, the IOA was standardized using methods described below.

A delta lognormal approach (Lo *et al.* 1992; Ingram *et al.* 2010) is used to standardize female SM catch-rates in each year as:

$$I_y = c_y p_y \quad [8]$$

where c_y are estimated annual mean CPUEs of non-zero female SM catches assumed as lognormal distributions and p_y are estimated annual mean probabilities of female SM capture assumed as binomial distributions. The lognormal and binomial means and their standard errors are estimated with generalized linear models as least squares means and back transformed. The lognormal model considers only samples in which SM were captured; the binomial model considers all samples. The IOA is then computed from equation [8] with variances approximated from a Monte Carlo resampling routine (2000 iterations) using the estimated least-square means and standard errors.

Variables considered in model inclusion were:

Factor	Levels	Value
Year	24	1988-2012
Month	4	November-February
Area	4	CSAs 1,5,6,7
Gear	4	1.0, 1.25, 1.5, 1.75” bar meshes
Salinity	Continuous	--
Temperature	Continuous	--

January and February samples are grouped with the previous year’s November and December samples for IOA development. This approximates survey timing at the end of the calendar year (December 31st).

To determine the most appropriate models, factors were selected using a forward step-wise approach where each factor was added to each sub-model individually and the resulting reduction in deviance per degree of freedom (Dev/DF) analyzed. The factor causing the greatest reduction in Dev/DF was then added to the base model. Criteria for model inclusion also included a reduction in Dev/DF ≥1% and a Chi-Square significance test ≤0.05. This procedure was then repeated until no factor met criteria for model inclusion. We assume that there are no significant interaction terms with year in this model and considered only the main effects.

Resulting sub-models are as follows:

$$c \sim Year + Area + Gear \quad [9]$$

$$p \sim Year + Area + Month + Gear + Salinity \quad [10]$$

Sub-models were estimated with the SAS generalized linear modeling procedure (PROC GENMOD; SAS 1994). Sample sizes, proportion positive samples, nominal CPUE, standardized index, and coefficients of variation of the standardized index are presented (Table 4). Standardized and nominal CPUEs, normalized to 1 for comparison, are also presented (Figure 3).

5. Catch at Age Estimation

Age-length-keys (ALKs) are developed to estimate the annual age composition/catch-at-age of fishery and survey catches as described below.

5.1 Fishery

Only female SM otoliths collected from fishery-dependent sources are used in age assignments of fishery landings in this assessment. Ages were assigned by assuming a January 1st birthday, where SM spawned the previous year become age-1 on January 1st and remain age-1 until the beginning of the following year.

Probabilities of age given length for annual fishery landings are computed as:

$$P(a|l)_y = \frac{n_{lay}}{\sum_a n_{lay}} \quad [11]$$

where n_{lay} are annual female SM sample sizes occurring in each length/age bin (Tables 5 and 6). Table 5 is used to calculate $P(a|l)_y$ for 1996-2002 landings, where limited annual sample sizes preclude use of annual ALKs. Annual fishery catch-at-age (females only) is then taken as:

$$C_{ay} = \sum_l P_{fem,l} C_{ly} \, P(a|l)_y \quad [12]$$

where $P_{fem,l}$ is taken from equation [4], C_{ly} is annual fishery catch-at-size, and $P(a|l)_y$ are taken from equation [11]. Resulting annual fishery catch-at-age and associated mean weights-at-age are presented (Tables 7 and 8).

5.2 Survey

Probabilities of age given length for female SM catches of the experimental marine gillnet survey are computed as:

$$P(a|l) = \frac{P(l|a)}{\sum_a P(l|a)} \quad [13]$$

with the probability of length given age estimated from a normal probability density as:

$$P(l|a) = \frac{1}{\sigma_a\sqrt{2\pi}} \int_{l-d}^{l+d} exp\left[-\frac{(l-l_a)^2}{2\sigma_a^2}\right] dl \quad [14]$$

where length bins are 1 inch TL intervals with midpoint l, maximum $l + d$, and minimum $l - d$ lengths. Mean length-at-age l_a is estimated from Equation [3]. The standard deviation in length-at-age is approximated from $\sigma_a = l_a CV_l$, where the coefficient of variation in length-at-age is assumed constant (in this case 0.05). To approximate changes in growth with the timing of the survey, mean l_a is calculated at the end of the calendar year (*i.e.,* age=$a + 1.0$). Resulting survey $P(a|l)$ is presented (Table 9). Annual survey female catch-at-age is then taken from equation [12] with annual survey catch-at-size as C_{ly}. Annual survey catch-at-size is derived using only those samples included in abundance index development. Annual survey catch-at-size and resulting annual survey age compositions (females only) are presented (Tables10 and 11).

6. Assessment Model

In this assessment update, the Age-Structured Assessment Program (ASAP3 Version 3.0.12; NOAA Fisheries Toolbox http://nft.nefsc.noaa.gov) is used to describe the dynamics of the female proportion of the LA SM stock. ASAP is a statistical catch-at-age model that allows internal estimation of a Beverton-Holt stock recruitment relationship and MSY-related reference points. Minimum data requirements are fishery catch-at-age, corresponding mean weights-at-age, and a tuning index. ASAP projects abundance at age from estimates of abundance in the initial year of the time-series and recruitment estimates in subsequent years. The model is fit to the data with a maximum likelihood fitting criterion. An overview of the basic model configuration, equations, and their estimation, as applied in this assessment, are provided below. Specific details and full capabilities of ASAP can be found in the technical documentation (ASAP3; NOAA Fisheries Toolbox).

6.1 Model Configuration

The model is configured with annual time-steps (1996-2013) and a calendar year time frame. As in earlier assessments, only the years 1996-2013 are modeled due to the limited size and age information available from earlier years of the fishery. Since the commercial SM strike net fishery season runs from the 3rd Monday in October through the 3rd Monday of the following January, SM harvested in January are grouped with the previous year's landings for modeling purposes.

Mortality

Fishing mortality is assumed separable by age a and year y as:

$$F_{ay} = v_a Fmult_y \quad [15]$$

where v_a are fishery selectivities and $Fmult_y$ are fully-selected fishing mortality rates. Apical fishing mortality is estimated in the initial year and as deviations from the initial estimate in subsequent years.

Age-specific fishery selectivities are modeled with a single logistic function as:

$$v_a = \frac{1}{1+e^{-(a-\alpha)/\beta}} \quad [16]$$

Total mortality for each age and year is estimated from the age-specific natural mortality rate M_a and estimated fishing mortalities as:

$$Z_{ay} = M_a + F_{ay} \quad [17]$$

For reporting purposes, annual fishing mortalities are averaged by weighting by population abundance as:

$$F_y = \frac{\sum_a F_{ay} N_{ay}}{\sum_a N_{ay}} \quad [18]$$

Abundance

Abundance in the initial year of the time series and recruitment in subsequent years are estimated and used to forward calculate the remaining numbers at age from the age and year specific total mortality rates as:

$$N_{ay} = N_{a-1,y-1} e^{-Z_{a-1,y-1}} \quad [19]$$

Numbers in the plus group A are calculated from:

$$N_{Ay} = N_{A-1,y-1} e^{-Z_{A-1,y-1}} + N_{A,y-1} e^{-Z_{A,t-1}} \quad [20]$$

Stock Recruitment

Expected recruitment is calculated from the Beverton-Holt stock recruitment relationship, reparameterized by Mace and Doonan (1988), with annual lognormal deviations as:

$$\hat{R}_{y+1} = \frac{\alpha SS_y}{\beta + SS_y} + e^{\delta_{y+1}} \quad [21]$$

$$\alpha = \frac{4\tau(SS_0/SPR_0)}{5\tau-1} \text{ and } \beta = \frac{SS_0(1-\tau)}{5\tau-1}$$

where SS_0 is unexploited spawning stock, SPR_0 is unexploited spawning stock per recruit, τ is steepness, and $e^{\delta_{y+1}}$ are annual lognormal recruitment deviations..

Spawning Stock

Spawning stock in each year is calculated from:

$$SS_y = \sum_{i=1}^{A} N_{ay} \Phi_{ay}\, e^{-Z_{ay}(0.0)} \quad [22]$$

where Φ_{ay} is per capita fecundity at age, and $-Z_{ay}(0.0)$ is the proportion of total mortality occurring prior to spawning on January 1st .

Catch

Expected fishery catches are estimated from the Baranov catch equation as:

$$\hat{C}_{ay} = N_{ay} F_{ay} \frac{(1-e^{-Z_{ay}})}{Z_{ay}} \quad [23]$$

Expected age composition of fishery catches are then calculated from $\frac{\hat{C}_{ay}}{\sum_a \hat{C}_{ay}}$. Expected yields are then computed as $\sum_a \hat{C}_{ay} \overline{W}_{ay}$, where $\overline{W}_{ay}$ are observed mean catch weights.

Catch-rates

Expected survey catch-rates are computed from:

$$\hat{I}_{ay} = q \sum_a N_{ay} (1 - e^{-Z_{ay}(1.0)}) v_a \quad [24]$$

where v_a are the age-specific survey selectivities, q is the estimated catchability coefficient, and $-Z_{ay}(1.0)$ is the proportion of the total mortality occurring prior to the time of the survey (December 31st midpoint) . Age-specific survey selectivities are modeled with a double logistic function as:

$$v_a = \left(\frac{1}{1+e^{-(a-\alpha)/\beta}}\right)\left(1 - \frac{1}{1+e^{-(a-\alpha 2)/\beta 2}}\right) \quad [25]$$

Expected survey age composition is then calculated as $\frac{\hat{I}_{ay}}{\sum_a \hat{I}_{ay}}$.

Parameter Estimation

The number of parameters estimated is dependent on the length of the time-series, number of fisheries and selectivity blocks modeled, and number of tuning indices modeled. Parameters are estimated in log-space and then back transformed. In this assessment, 50 parameters are estimated:

1. 6 selectivity parameters (2 for the fishery; 4 for the survey)
2. 18 apical fishing mortality rates (F_{mult} in the initial year and 17 deviations in subsequent years)

3. 18 recruitment deviations (1996-2013)
4. 6 initial population abundance deviations (age-2 through 7-plus)
5. 1 catchability coefficient
6. 1 stock-recruitment parameter (virgin stock size; the steepness parameter is fixed at 1.0 for the base run).

The model is fit to the data by minimizing the objective function:

$$-ln(L) = \sum_i \lambda_i(-ln\, L_i) + \sum_j(-ln\, L_j) \quad [26]$$

where $-ln(L)$ is the entire negative log-likelihood , lnL_i are log-likelihoods of lognormal estimations, λ_i are user-defined weights applied to lognormal estimations, and lnL_j are log-likelihoods of multinomial estimations.

Negative log-likelihoods with assumed lognormal error are derived (ignoring constants) as:

$$-ln(L_i) = 0.5 \sum_i \frac{[ln(obs_i) - ln(pred_i)]^2}{\sigma^2} \quad [27]$$

where obs_i and $pred_i$ are observed and predicted values; standard deviations σ are user-defined CVs as $\sqrt{ln(CV^2 + 1)}$.

Negative log-likelihoods with assumed multinomial error are derived (ignoring constants) as:

$$-ln(L_j) = -ESS \sum_{i=1}^{A} p_i \, ln(\hat{p}_i) \quad [28]$$

where p_i and $\hat{p}_i$ are observed and predicted age composition. Effective sample-sizes ESS are used to create the expected numbers $\hat{n}_a$ in each age bin and act as multinomial weighting factors.

6.2 Model Assumptions/Inputs

Model assumptions include: 1) the unit stock is adequately defined and closed to migration, 2) observations are unbiased, 3) errors are independent and their structures are adequately specified, 4) fishery vulnerabilities are flat topped; survey vulnerabilities are dome-shaped, 5) abundance indices are proportional to absolute abundance, and 6) natural mortality, fecundity, growth and sex ratio at size/age do not vary significantly with time. Lognormal error is assumed for catches, abundance indices, the stock-recruitment relationship, apical fishing mortality, selectivity parameters, initial abundance deviations, and catchability. Multinomial error is assumed for fishery and survey age compositions.

The base model was defined with an age-7 plus group, steepness fixed at 1.0, one fishery selectivity block, one survey selectivity block, and input levels of error and weighting factors as described below. Input levels of error for fishery landings were specified with CV's of 0.05 for each year of the time-series;

annual recruitment deviations were specified with CV's of 0.5. All lambdas for lognormal components included in the objective function were equally weighted (=1). Input effective sample sizes for estimation of fishery age compositions were specified as ESS=50 for years where annual ALKs were available (2003-2013) and down weighted to ESS=25 for years where the pooled ALK was used (1996-2002). Input effective sample size for estimation of survey age compositions, where ages were assigned from a von Bertalanffy growth function, were specified as ESS=10.

6.3 Model Results

Objective function components, weighting factors, and likelihood values of the base model are summarized in Table 12.

Model Fit

The base model provides an overall reasonable fit to the data. Predicted catches match the observations well, with no strong pattern in residuals (Figure 4). Predicted survey catch-rates also match the data well with no strong pattern in residuals, but fail to fit the high catch rate observed in 2005 (Figure 5). Predicted fishery and survey age compositions provide good fits to the input age proportions (Figures 6 and 7).

Selectivities

Estimated fishery and survey selectivities are presented in Figure 8. Fishery estimates indicate full-vulnerability to the commercial gill net fishery at age 5 with over 50% vulnerable at age 3. Survey estimates indicate full vulnerability to the FI survey gear at age 2.

Abundance, Recruitment, and Spawning Stock

Total stock size and abundance at age estimates from the base model are presented in Table 13. Stock size has varied over the time-series. Stock size decreased from 27.2 million females in 1996 to a minimum of 16.3 million females in 2004. Since 2004, stock size increased to a peak of 24.8 million females in 2012. The 2013 estimate of stock size is 20.2 million females.

Recruitment estimates from the base model are presented in Figure 9. Recruitment has varied over the time-series. Age-1 recruit estimates decreased from 10.7 million fish in 1996 to 5.7 million age-1 fish in 2003. Since 2003, recruitment increased to a peak of 12.3 million age-1 fish estimated in 2006. The 2013 estimate of age-1 recruits is the lowest of the time-series (4.0 million fish).

Spawning stock estimates (total egg production) are presented in Figure 10. Spawning stock has varied over the time series with a decreasing trend in early years to an increasing trend in later years. Spawning stock decreased from 4.8 trillion eggs in 1996 to a minimum of 2.8 trillion eggs in 2005. Since 2005, the trend has been upward with an estimate of 7.8 trillion eggs in 2013.

Fishing Mortality

Estimated fishing mortality rates are presented in Table 14 (apical, average, and age-specific) and Figure 11 (average only). Average rates are weighted by population numbers at age. Average fishing mortality has varied over the time-series with an overall decreasing trend. The highest estimates of F were in earlier years of the time series with a peak observed in 1999 (0.26 yr^{-1}). Since 1999, average fishing mortality rates decreased to a minimum of 0.004 yr^{-1} in 2009 and has remained low. The 2013 estimate of average F is 0.02 yr^{-1}.

Stock-Recruitment

No discernable relationship is observed between spawning stock and subsequent age-1 recruitment (Figure 12). The ASAP base model was run with steepness fixed at 1.0. The unexploited spawning stock estimate was 10.8 trillion eggs. When allowed to directly solve for steepness, the parameter was estimated as 1.0. Alternate runs with steepness values fixed at 0.9, 0.8, and 0.7 are discussed in the *Model Diagnostics* Section below.

Parameter Uncertainty

In the ASAP base model, 50 parameters were estimated. Asymptotic standard errors for the time-series of age-1 recruits are presented in Figure 9. Markov Chain Monte Carlo derived confidence intervals (95%) for average fishing mortality rates and the spawning stock time-series are presented in Figures 10 and 11.

6.4 Management Benchmarks

The conservation standard established by the LA Legislature for striped mullet (RS 56:333) is a 30% spawning potential ratio (SPR; Goodyear 1993). Methodology used in this assessment to estimate equilibrium yield, spawning stock (total egg production), and fishing mortality rates that lead to 30% SPR are described below. Current conditions are taken by averaging estimates from the final three years of the modeled time-series (2011-2013).

When the stock is in equilibrium, equation [22] can be solved, excluding the year index, for any given exploitation rate as:

$$\frac{SS}{R}(F) = \sum_{i=1}^{A} N_a \Phi_a \, e^{-Z_a(0.0)} \quad [29]$$

where total mortality at age Z_a is computed as $M_a + v_a Fmult$; vulnerability at age v_a is taken by rescaling the current F-at-age estimate (geometric mean 2011-2013) to the maximum. Per recruit abundance-at-age is estimated as $N_a = S_a$, where survivorship at age is calculated recursively from $S_a = S_{a-1} e^{-Z_a}$, $S_1 = 1$. Per recruit catch-at-age is then calculated with the Baranov catch equation [23], excluding the year index. Yield per recruit (Y/R) is then taken as $\sum_a C_a \bar{W}_a$ where $\bar{W}_a$ are current mean fishery weights at age (arithmetic mean 2011-2013).

Equilibrium spawning stock SS_{eq} is calculated by substituting SS/R estimated from equation [29] into the Beverton-Holt stock recruitment relationship as $\alpha \times SS/R - \beta$. Equilibrium recruitment R_{eq} and yield Y_{eq} are then taken as $SS_{eq} \div SS/R$ and $Y/R \times R_{eq}$. Fishing mortality is averaged as $\sum_a F_a N_a / \sum_a N_a$. Equilibrium SPR is then computed as the ratio of SS/R when F>0 to SS/R when F=0.

As reference points to guide management, we estimate the average fishing mortality rate, spawning stock size, and yield that lead to a 30% SPR ($F_{30\%}$, $SS_{30\%}$, and $Y_{30\%}$). These estimates are presented in Figure 14 relative to each respective time-series. Also presented are a plot of the stock recruitment data, equilibrium recruitment, and diagonals from the origin intersecting R_{eq} at the minimum and maximum spawning stock estimates of the time-series, corresponding with a minimum equilibrium SPR of 26% and a maximum of 72% (Figure 13). The current estimate of equilibrium SPR is 68%. Estimates of $F_{30\%}$ and $SS_{30\%}$ are also presented in Table 15.

6.5 Model Diagnostics

Sensitivity Analysis

A series of sensitivity runs are used to explore uncertainty in the base model's configuration. The ASAP base model was run with steepness fixed at 1.0. When allowed to directly solve for steepness, the parameter was estimated as 1.0. Alternate runs were conducted examining reference point estimates ($F_{30\%}$, $SS_{30\%}$, $Y_{30\%}$, $F_{current}/F_{30\%}$, and $SS_{current}/SS_{30\%}$) with steepness fixed at 0.9, 0.8 and 0.7. Current conditions are taken by averaging estimates from the final three years of the modeled time-series (2011-2013). Additional sensitivity runs were conducted by separately increasing the lognormal weighting factors of the catch and IOA components of the base models objective function (*i.e.*, lambdas increased from 1 to 4).

Results of the sensitivity analysis are presented in Table 16. Reference point estimates from all other sensitivity runs indicate the stock is currently above $SS_{30\%}$ and the fishery is currently operating below $F_{30\%}$. Estimates of $F_{30\%}$, $SS_{30\%}$, and $Y_{30\%}$ for each sensitivity run were similar in magnitude (0.15 yr^{-1}, 2.0-3.6 trillion eggs, and 3.1-3.8 million pounds, respectively).

Retrospective Analysis

A retrospective analysis was conducted by sequentially truncating the base model by a year (terminal years 2009-2012). Retrospective estimates of recruitment, $SS/SS_{30\%}$, and $F/F_{30\%}$ are presented in Figure 14, where $SS_{30\%}$ and $F_{30\%}$ are computed from the base model run. Estimated terminal year $SS/SS_{30\%}$,

$F/F_{30\%}$, and recruitment differed from the full base run. Terminal year $SS/SS_{30\%}$ estimates indicate positive bias for the 2011-2009 retrospective runs, where $SS/SS_{30\%}$ decreases as more years are added to the model. Terminal year $F/F_{30\%}$ estimates indicate negligible bias, where $F/F_{30\%}$ generally decreases as more years are added to the model. Terminal year recruitment estimates indicate positive bias for the 2011 and 2010 runs and negative bias for the 2009 model run.

7. Stock Status

The history of the LA striped mullet stock relative to $F/F_{30\%}$ and $SS/SS_{30\%}$ is presented in Figure 15. Given the established conservation standard of 30% SPR, fishing mortality rates exceeding $F_{30\%}$ ($F/F_{30\%}$>1.0) are defined as overfishing; spawning stock sizes below $SS_{30\%}$ ($SS/SS_{30\%}$< 1.0) are defined as the overfished condition.

Overfishing Status

Using results of the ASAP model presented in this assessment, the current estimate of $F/F_{30\%}$ is <1.0, suggesting the stock is currently not undergoing overfishing. However, the assessment model indicates that the stock did experience overfishing in earlier years of the time-series.

Overfished Status

The 2012 estimate of $SS/SS_{30\%}$ is >1.0, suggesting the stock is currently not in an overfished state. However, the assessment model indicates that the stock was in an overfished state in earlier years of the time-series.

Control Rules

As specified in RS 56:333 (http://www.legis.la.gov/Legis/Law.aspx?d=105230), if the annual LDWF striped mullet stock assessment indicates that the current spawning potential ratio is <30%, the department shall close the season within two weeks for a period of at least one year.

8. Research and Data Needs

As with any analysis, the accuracy of this assessment is dependent on the accuracy of the information of which it is based. Mapes et al. (1998) identify several areas for research to address. Below we list additional recommendations to improve future LA assessments of striped mullet.

Only limited age data are available from the LDWF marine gillnet survey. Ages of survey catches in this assessment were assigned from a von Bertalanffy growth function. Age samples collected directly from the survey in question would allow a more accurate representation of survey age composition in future assessments.

Methods to characterize fishery catch at age for years prior to 1996 need to be examined. Inclusion of years prior to the 1995 peak in commercial striped mullet landings in the assessment model should provide better contrast in spawning stock size and allow more certainty in reference point estimation.

Factors that influence year-class strength of striped mullet are poorly understood. Investigation of these factors, including inter-annual variation in seasonal factors and the influence of environmental perturbations such as the Deepwater horizon oil spill, could elucidate causes of inter-annual variation in abundance, as well as the species stock-recruitment relationship.

Fishery-dependent data alone is not a reliable source of information to assess status of a fish stock. Consistent fishery-dependent and fishery-independent data sources, in a comprehensive monitoring plan, are essential to understanding the status of fishery. A new LDWF fishery-independent survey methodology was implemented in 2013. This methodology should be assessed for adequacy with respect to its ability to evaluate stock status, and modified if deemed necessary.

With the recent trend toward ecosystem-based assessment models, more data is needed linking striped mullet population dynamics to environmental conditions. The addition of meteorological and physical oceanographic data coupled with food web data may lead to a better understanding of the striped mullet stock and its habitat.

9. References

Campton, D. and B. Mahmoudi. 1991. Allozyme variation and population structure of striped mullet (*Mugil cephalus*) in Florida. Copeia 2:485-492.

Goodyear, C.P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. *pp* 67-81 *in* S.J. Smith, J.J. Hunt and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Canadian Special Publication of Fisheries and Aquatic Sciences. 442 pp.

GSMFC. 1995. The striped mullet fishery of the Gulf of Mexico, United States: a regional management plan. Publication No. 33. Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi, 204 pp.

Ingram, G. W., Jr., W. J. Richards, J. T. Lamkin, and B. Muhling. 2010. Annual indices of Atlantic bluefin tuna (*Thunnus thynnus*) larvae in the Gulf of Mexico developed using delta-lognormal and multivariate models. Aquat. Living Resour. 23:35–47.

LDWF. 2002. Marine Fisheries Division Field Procedures Manual. Louisiana Department of Wildlife and Fisheries, Version 02-1, Baton Rouge, LA.

Lo, N.C.H., Jacobson, L.D., and Squire, J.L. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Canadian Journal of Fisheries and Aquatic Science 49:2515–2526.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49:627-642.

Mace, P.M., and Doonan, I.J. 1988. A generalized bioeconimic simulation model for fish population dynamics. Technical Report 88, New Zealand Fisheries Assessment Resource Document.

Mapes, K. A., R. Bejarano, J. F. Burdon and B. McManus. 1998. A biological and fisheries profile for striped mullet, *Mugil cephalus* in Louisiana. La. Dept. of Wildl. & Fish., Office of Fisheries, Fishery Management Plan Series No. 5, Part 1.

NMFS. 2014a. Annual commercial landings statistics. National Marine Fisheries Service, Fisheries Statistics and Economics Division. Available: www.st.nmfs.gov [accessed 8/21/2014].

NMFS. 2014b. Marine recreational fisheries statistical survey. National Marine Fisheries Service, Fisheries Statistics and Economics Division. Available: www.st.nmfs.gov [accessed 8/21/2014].

NOAA Fisheries Toolbox. 2013. Age Structured Assessment Program (ASAP), Version 3.0.12. Available: www.nft.nefsc.noaa.gov .

SEDAR. 2006. Gulf of Mexico Vermilion Snapper SEDAR 9 Assessment Report 3. SEDAR, Charleston, SC. Available at http://www.sefsc.noaa.gov/sedar/

SEDAR, 2006. Stock Assessment of Gulf of Mexico Red Grouper. SEDAR, Charleston, SC. Available at http://www.sefsc.noaa.gov/sedar/

Thompson, B. A., J. H. Render, R. L. Allen and D.L. Nieland. 1991. Fisheries independent characterization of population dynamics and life history of striped mullet in Louisiana. Final Report, MARFIN project NA90AA-H-MF-113. 92 pp.

West, J., J. Adriance, K. Lewis, & J.E. Powers. 2014. Assessment of striped mullet in Louisiana waters. 2014 Report of the Louisiana Department of Wildlife and Fisheries. 41 pp.

<u>10. Tables</u>

Table 1: Annual Louisiana commercial and recreational striped mullet *Mugil cephalus* landings (pounds x 10^3) derived from NMFS statistical records, LDWF trip ticket program, and MRFSS/MRIP. Recreational landings are A+B1 catches only.

	Harvest		
Year	Commercial	Recreational	%_Recreational
1981	3,051	1	0.0%
1982	1,533	17	1.1%
1983	1,887	0	0.0%
1984	3,157	3	0.1%
1985	579	8	1.3%
1986	2,278	53	2.3%
1987	1,439	0	0.0%
1988	2,367	106	4.3%
1989	2,414	75	3.0%
1990	2,646	296	10.1%
1991	3,563	26	0.7%
1992	6,215	121	1.9%
1993	11,026	185	1.7%
1994	12,560	98	0.8%
1995	14,546	90	0.6%
1996	8,659	217	2.4%
1997	8,083	130	1.6%
1998	6,252	15	0.2%
1999	8,954	49	0.5%
2000	7,253	88	1.2%
2001	4,260	116	2.6%
2002	2,555	59	2.3%
2003	4,524	3	0.1%
2004	4,754	3	0.1%
2005	1,238	13	1.0%
2006	3,361	2	0.1%
2007	1,375	391	22.1%
2008	1,503	1	0.1%
2009	189	36	16.2%
2010	362	12	3.2%
2011	1,385	18	1.3%
2012	1,394	50	3.5%
2013	593	77	11.5%

Table 2: Annual size frequency samples of Louisiana commercial striped mullet *Mugil cephalus* landings derived from the Trip Interview Program (TIPS; 1996-2001), the Fishery Information Network (FIN; 2007-2013), and by combination of data collection programs (TIPS+FIN; 2002-2006).

TL_in	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
6																		
7																		
8																		
9																		
10	3																	2
11	8	2	1										1					1
12	59	44	1	10				3	1		10	8	7		1	1	1	8
13	271	183	5	20	1	3	11	30	22	11	25	25	35		26	22	19	38
14	518	537	45	37	9	20	37	101	68	61	53	78	103	1	50	39	45	131
15	401	595	73	114	40	41	49	142	122	151	107	194	150	10	23	40	112	255
16	308	453	110	244	83	40	53	169	267	182	164	256	155	49	41	94	153	276
17	202	230	126	248	87	75	31	151	342	154	135	187	160	165	33	254	260	181
18	121	108	94	259	73	41	7	110	209	117	117	127	106	215	34	330	244	43
19	61	36	36	148	43	18	4	36	58	19	47	74	37	134	6	118	63	5
20	14	14	6	49	16	1		8	20		15	12	16	79	1	19	5	
21	6	3		13	2				2		1	2	1	20		3		
22	2			2	1							1		6			2	
23													1	1				
24	1																	
25																		
26																		
27	2																	
28																		
Totals	1977	2205	497	1144	355	239	192	750	1111	695	674	964	772	680	215	920	904	940

Table3: FAO proposed guidelines for indices of productivity for exploited fish species.

Parameter	**Productivity**			**Species**	
	Low	**Medium**	**High**	Striped Mullet	**Score**
M	<0.2	0.2 - 0.5	>0.5	**0.3**	2
K	<0.15	0.15 - 0.33	>0.33	**0.28**	2
tmat	>8	3.3 - 8	<3.3	**2**	3
tmax	>25	14 - 25	<14	**10**	3
Examples	orange roughy, many sharks	cod, hake	sardine, anchovy	**Striped Mullet Productivity Score = 2.5 (med/high)**	

Table 4: Annual sample size, proportion positive samples, nominal CPUE, index of abundance, and corresponding coefficients of variation derived from the LDWF fishery-independent marine gillnet survey. Nominal cpue and the index of abundance have been normalized to their individual long-term means for comparison.

Year	n	%Positive	Nominal CPUE	Index	CV
1988	901	21%	0.49	0.98	0.12
1989	939	19%	0.58	0.82	0.12
1990	987	20%	0.69	1.00	0.11
1991	1020	20%	0.82	0.86	0.11
1992	700	21%	0.72	0.85	0.13
1993	663	21%	0.68	0.79	0.14
1994	644	22%	1.36	0.95	0.13
1995	508	27%	1.47	1.46	0.14
1996	520	19%	0.43	0.56	0.16
1997	544	19%	2.54	1.27	0.16
1998	560	23%	0.91	1.02	0.14
1999	560	16%	1.05	1.09	0.17
2000	532	19%	1.16	1.39	0.16
2001	560	16%	1.56	0.66	0.16
2002	560	20%	0.84	0.65	0.15
2003	560	16%	1.14	0.72	0.17
2004	560	21%	0.81	0.86	0.15
2005	536	24%	1.02	2.20	0.15
2006	560	19%	1.26	1.04	0.16
2007	552	21%	0.99	1.16	0.15
2008	560	16%	0.87	1.05	0.16
2009	548	16%	0.75	0.44	0.17
2010	524	19%	1.74	1.50	0.16
2011	528	20%	0.76	1.13	0.16
2012	528	19%	0.60	0.94	0.16
2013	600	16%	0.74	0.64	0.16

Table 5: Length-at-age samples used for age assignments of commercial striped mullet *Mugil cephalus* landings 1996-2002 (females only).

	1996-2002										
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12		4	2	1							7
13		21	27	6	1						55
14		28	65	35	4	1		1			134
15	2	28	43	28	6	4	1				112
16	1	18	29	20	8	2					78
17		7	34	15	6	5	2				69
18		3	23	21	9	2					58
19		1	8	11	7	3	1				31
20				2	4	2		1			9
21			1	1	1		1	1			5
22											
23											
24											
25											
26											
Total	3	110	232	140	46	19	5	3	0	0	558

Table 6: Annual length-at-age samples for age assignments of commercial striped mullet *Mugil cephalus* landings 2003-2013 (females only).

2003											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12		1	1	1							3
13		13	3	4	3						23
14		9	18	17	6						50
15		6	34	18	4	1					63
16		3	37	38	20	3					101
17		4	17	40	29	6		1			97
18		1	8	20	26	4	8	2			69
19		3	5	6	8	6	3				31
20				2	1	2	1				6
21											
22											
23											
24											
25											
26											
Total	0	40	123	146	97	22	12	3	0	0	443

2004											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13		1	4								5
14		2	10	4	3	2					21
15		6	28	12	5	3					54
16		5	24	33	13	8					83
17		2	37	58	32	9					138
18			14	47	34	27	1				123
19			2	10	15	9	3				39
20				2	6	4	1				13
21						1					1
22											
23											
24											
25											
26											
Total	0	16	119	166	108	63	5	0	0	0	477

2005											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13	1	1	1								3
14		18	4	7	4						33
15		53	34	41	12						140
16		14	50	69	30	11	2				176
17		4	35	62	36	8	6				151
18			8	49	37	16	5	1			116
19				2	9	2	4				17
20											
21											
22											
23											
24											
25											
26											
Total	1	90	132	230	128	37	17	1	0	0	636

Table 6 (continued):

2006											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13		5	3	2	1						11
14	1	2	5	4	4						16
15		22	27	13	20	3	1				86
16		22	39	42	33	8	1				145
17		11	35	31	33	14	2	2			128
18		1	18	44	35	9	3				110
19				13	17	11	3	2			46
20					5	3	5				13
21								1			1
22											
23											
24											
25											
26											
Total	1	63	127	149	148	48	15	5	0	0	556

2007											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12		2	1	2							5
13	1	6	3		1	1					12
14	1	17	12	6	3	2					41
15	2	51	48	15	13	6					135
16		48	71	55	22	21	1			1	219
17		10	48	48	32	27	6				171
18	1	3	12	31	30	27	6	3			113
19	1	1	1	9	22	21	9				64
20				1	2	3	2	1	1		10
21		1	1								2
22						1					1
23											
24											
25											
26											
Total	6	139	197	167	125	109	24	4	1	1	773

2008											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12		1	2	1							4
13		4	17	6	1						28
14		4	55	26	2						87
15		9	93	19	6	2					129
16	1	8	84	36	4	4	1				138
17		1	73	43	16	6	2				141
18			33	37	7	10	2	1			90
19			9	7	10	5					31
20			3	3	2	3	1	2			14
21			1								1
22											
23			1								1
24											
25											
26											
Total	1	27	371	178	48	30	6	3	0	0	664

Table 6 (continued):

2009											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13											
14											
15		1									1
16			3	4							7
17	1	2	25	17	4	1					50
18		1	15	45	4	1	1				67
19			2	25	5	3	1				36
20				9	8	1					18
21				2	1	3	2	1			9
22		1						2			3
23											
24											
25											
26											
Total	1	5	45	102	22	9	4	3	0	0	191

2010											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12					1						1
13		1	9	11	4	1					26
14		4	18	15	12	1					50
15			3	15	5						23
16		2	11	22	4	2					41
17			5	18	9	1					33
18				12	18	3		1			34
19					6						6
20						1					1
21											
22											
23											
24											
25											
26											
Total	0	7	46	93	59	9	0	1	0	0	215

2011											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13	1	8	3								12
14		9	8	3	1						21
15		2	5	7	5		1				20
16		1	16	15	30	4	1	1			68
17		1	18	48	103	22	3	1			196
18		1		21	140	91	15	1			269
19			2	4	29	54	9				98
20					6	9	2				17
21				1		1					2
22											
23											
24											
25											
26											
Total	1	22	52	99	314	181	31	3	0	0	703

Table 6 (continued):

2012											
TL_in	*Age_1*	*Age_2*	*Age_3*	*Age_4*	*Age_5*	*Age_6*	*Age_7*	*Age_8*	*Age_9*	*Age_10*	*Total*
8											
9											
10											
11											
12											
13		3	1		1	1					6
14	1	15	16	5	1		1				39
15		29	47	14	9	5	2				106
16		7	55	37	21	12	6				138
17		3	24	69	60	49	10				215
18			4	23	39	96	31	1	1		195
19				1	6	17	18	2			44
20						1	2				3
21											
22			1								1
23											
24											
25											
26											
Totals	1	57	148	149	137	181	70	3	1	0	747

2013											
TL_in	*Age_1*	*Age_2*	*Age_3*	*Age_4*	*Age_5*	*Age_6*	*Age_7*	*Age_8*	*Age_9*	*Age_10*	*Total*
8											
9											
10			1								1
11											
12			1								1
13		6	1	3							10
14		31	17	1	2						51
15		53	61	21	6	1					142
16		15	67	34	11	5	2				134
17		5	28	40	18	5	4				100
18			4	16	10	5	3				38
19					2	2	1				5
20											
21											
22											
23											
24											
25											
26											
Totals	0	110	180	115	49	18	10	0	0	0	482

Table 7: Commercial striped mullet *Mugil cephalus* catch-at-age and yield (females only).

	Commercial Catch-at-age (Females only)							
Year	*Age_1*	*Age_2*	*Age_3*	*Age_4*	*Age_5*	*Age_6*	*Age_7+*	*Yield (lbs)*
1996	27,596	1,059,061	2,014,009	1,150,059	337,810	139,953	50,207	6,877,195
1997	32,981	949,646	1,822,990	1,072,076	309,034	132,590	41,343	6,304,535
1998	15,061	418,799	1,158,810	778,530	313,266	135,508	38,239	5,183,043
1999	16,685	483,980	1,450,924	1,087,935	531,781	218,917	85,349	7,690,198
2000	14,901	387,925	1,178,110	872,077	425,744	182,186	63,538	6,173,000
2001	10,008	285,467	832,422	537,857	209,205	98,098	28,938	3,621,739
2002	11,128	280,941	575,874	340,062	103,301	46,247	12,795	2,065,852
2003	.	184,808	661,712	746,976	480,586	103,494	72,363	3,812,452
2004	.	85,724	595,288	775,601	467,803	257,873	17,516	4,043,336
2005	167	90,765	120,788	210,797	118,924	33,814	16,841	1,010,382
2006	7,022	190,894	375,604	423,423	417,454	126,499	51,332	2,839,539
2007	5,750	125,396	166,397	136,819	103,360	88,574	25,279	1,139,848
2008	1,097	30,194	411,375	202,793	56,757	36,267	11,125	1,277,838
2009	313	1,302	15,707	35,739	8,219	3,011	1,623	153,084
2010	.	5,755	37,248	78,535	50,522	7,166	1,104	285,467
2011	954	22,062	47,684	84,815	259,970	147,093	28,586	1,207,707
2012	707	44,193	111,418	122,604	118,784	162,894	67,816	1,185,806
2013	.	77,825	119,646	74,215	29,839	10,272	5,890	485,797

Table 8: Mean weight-at-age (pounds) of commercial striped mullet *Mugil cephalus* landings (females only).

	Commercial Mean Weight-at-age (Females only)						
Year	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+
1996	1.43	1.23	1.39	1.52	1.83	1.84	2.05
1997	1.43	1.30	1.41	1.49	1.73	1.74	1.86
1998	1.47	1.56	1.77	1.87	2.05	2.02	2.06
1999	1.50	1.62	1.89	2.04	2.27	2.25	2.63
2000	1.49	1.67	1.89	2.02	2.24	2.23	2.49
2001	1.45	1.58	1.78	1.86	2.02	1.97	1.98
2002	1.45	1.40	1.49	1.54	1.69	1.71	1.70
2003	.	1.35	1.53	1.69	1.87	2.14	2.31
2004	.	1.43	1.62	1.87	2.00	2.04	2.66
2005	0.89	1.31	1.61	1.75	1.89	1.99	2.15
2006	1.10	1.42	1.62	1.83	1.89	2.12	2.41
2007	1.51	1.41	1.58	1.80	1.97	2.04	2.39
2008	1.60	1.29	1.60	1.76	2.01	2.19	2.39
2009	1.89	2.06	2.01	2.33	2.62	2.79	3.09
2010	.	1.21	1.30	1.56	1.82	1.81	2.36
2011	0.89	1.15	1.57	1.87	2.08	2.33	2.28
2012	1.10	1.30	1.54	1.83	1.96	2.12	2.26
2013	.	1.27	1.50	1.67	1.77	1.88	1.89

Table 9: Probabilities of age given length for age assignments of female striped mullet *Mugil cephalus* catches from the LDWF fishery-independent marine gillnet survey.

TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+
6	1.00	0.00	0.00	0.00	0.00	0.00	0.00
7	1.00	0.00	0.00	0.00	0.00	0.00	0.00
8	1.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	1.00	0.00	0.00	0.00	0.00	0.00
11	0.00	1.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.81	0.19	0.00	0.00	0.00	0.00
13	0.00	0.01	0.96	0.03	0.00	0.00	0.00
14	0.00	0.00	0.69	0.30	0.01	0.00	0.00
15	0.00	0.00	0.07	0.74	0.17	0.02	0.00
16	0.00	0.00	0.00	0.31	0.48	0.16	0.05
17	0.00	0.00	0.00	0.02	0.31	0.34	0.33
18	0.00	0.00	0.00	0.00	0.05	0.20	0.76
19	0.00	0.00	0.00	0.00	0.00	0.04	0.96
20	0.00	0.00	0.00	0.00	0.00	0.00	1.00
21	0.00	0.00	0.00	0.00	0.00	0.00	1.00
22	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 10: Annual female striped mullet *Mugil cephalus* catch-at-size derived from the LDWF fishery-independent marine gillnet survey.

TL_in / Year	1996	1997	1998	1999	2000	2001	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
5	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
6	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
7	2	2	6	8	2	63	16	20	3	5	8	8	19	7	9	24	6	2
8	25	32	43	94	26	124	87	83	31	52	118	98	62	30	103	87	49	14
9	16	23	43	47	27	37	37	47	23	38	46	56	22	21	75	24	23	16
10	24	90	88	42	97	110	46	95	64	103	103	82	57	66	204	35	40	46
11	16	178	43	38	58	85	23	65	42	62	84	50	36	56	91	25	42	64
12	21	296	54	56	64	60	26	25	58	92	49	52	51	34	96	35	42	53
13	23	155	54	30	54	15	35	22	36	61	30	30	30	14	28	29	13	31
14	13	73	37	15	45	9	36	14	25	41	25	19	12	11	9	14	4	16
15	9	37	14	6	37	9	22	7	18	20	15	15	3	2	8	9	3	10
16	5	30	19	4	23	3	8	2	24	3	.	4	1	1	3	7	1	5
17	1	20	19	1	3	1	.	.	13	2	1	.	1	.	.	2	.	.
18	1	3	2	.	1	.	3	.	4	2	1	1	.	1	.	.	.	.
19	.	1	1	1	1	.	.	.	1	.	.	.	.	.	.	.	.	.
20	1	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
21	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
22	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Totals	156	941	423	343	438	516	339	379	341	479	480	415	294	241	627	291	225	257

Table 11: Annual female striped mullet survey age composition and sample sizes derived from the LDWF fishery-independent marine gillnet survey.

Year	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+	n
1996	0.27	0.37	0.23	0.08	0.03	0.01	0.01	156
1997	0.06	0.54	0.28	0.07	0.03	0.01	0.01	940
1998	0.22	0.41	0.21	0.07	0.04	0.02	0.02	423
1999	0.44	0.36	0.15	0.03	0.01	0.00	0.01	343
2000	0.13	0.47	0.22	0.11	0.04	0.01	0.01	438
2001	0.44	0.47	0.06	0.02	0.01	0.00	0.00	516
2002	0.41	0.27	0.19	0.09	0.02	0.01	0.01	339
2003	0.40	0.47	0.10	0.03	0.01	0.00	0.00	379
2004	0.17	0.45	0.19	0.09	0.06	0.03	0.03	341
2005	0.20	0.50	0.22	0.06	0.01	0.00	0.00	479
2006	0.36	0.47	0.12	0.04	0.01	0.00	0.00	480
2007	0.39	0.42	0.13	0.05	0.01	0.00	0.00	415
2008	0.35	0.45	0.16	0.02	0.00	0.00	0.00	294
2009	0.24	0.62	0.12	0.02	0.00	0.00	0.00	241
2010	0.30	0.59	0.08	0.02	0.00	0.00	0.00	627
2011	0.46	0.30	0.16	0.05	0.02	0.01	0.00	291
2012	0.35	0.52	0.11	0.02	0.00	0.00	0.00	225
2013	0.12	0.59	0.20	0.06	0.02	0.00	0.00	257

Table 12: Summary of objective function components and negative log-likelihood values of the ASAP base model.

Objective function =1369			
Component	**Lambda**	**ESS**	**Obj_fun**
Catch_Fleet_Total	1		-40
Index_Fit_Total	1		26
Catch_Age_Comps		725	1147
Index_Age_Comps		180	246
Recruit_devs	1		-10

Table 13: Annual female striped mullet abundance-at-age and stock size estimates from the ASAP base model.

Year	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+	Totals
1996	10,790,500	6,850,550	5,587,870	2,617,240	871,758	322,702	162,543	27,203,163
1997	10,830,900	6,560,390	4,226,020	2,310,920	825,183	270,473	153,672	25,177,558
1998	8,841,060	6,584,840	4,045,870	1,744,820	726,728	255,335	133,996	22,332,649
1999	10,439,900	5,386,070	4,163,830	1,932,920	688,487	284,906	155,928	23,052,041
2000	8,212,000	6,343,370	3,297,750	1,648,200	569,305	198,968	130,032	20,399,625
2001	7,151,640	4,990,540	3,892,240	1,321,850	495,005	167,905	99,084	18,118,264
2002	7,445,350	4,358,920	3,173,990	1,923,290	549,666	204,966	112,988	17,769,170
2003	5,707,850	4,547,690	2,846,040	1,828,060	1,014,910	291,782	172,614	16,408,946
2004	7,156,950	3,479,280	2,895,920	1,416,520	768,745	425,192	198,853	16,341,460
2005	7,396,470	4,359,940	2,199,160	1,380,170	556,838	300,194	248,883	16,441,655
2006	12,302,900	4,524,560	2,898,930	1,408,290	858,862	351,039	354,549	22,699,130
2007	10,251,100	7,506,910	2,916,860	1,550,210	662,149	404,225	339,988	23,631,442
2008	5,568,740	6,271,860	5,001,750	1,890,700	983,056	425,725	490,151	20,631,982
2009	5,652,850	3,407,930	4,191,500	3,299,820	1,232,320	650,389	621,258	19,056,067
2010	8,258,860	3,462,820	2,305,220	2,967,260	2,399,940	914,031	966,954	21,275,085
2011	9,990,490	5,058,630	2,339,030	1,618,480	2,130,510	1,756,380	1,411,550	24,305,070
2012	8,952,360	6,116,040	3,395,050	1,581,750	1,096,220	1,467,170	2,235,020	24,843,610
2013	3,960,420	5,480,490	4,104,510	2,295,180	1,070,840	754,546	2,614,810	20,280,796

Table 14: Annual female striped mullet age-specific, apical, and average fishing mortality rates estimated from the ASAP base model.

Year	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+	Fmult	Avg. F
1996	0.01	0.09	0.54	0.84	0.88	0.88	0.88	0.88	0.26
1997	0.01	0.09	0.54	0.85	0.88	0.89	0.89	0.89	0.24
1998	0.01	0.07	0.40	0.62	0.65	0.65	0.65	0.65	0.18
1999	0.01	0.10	0.59	0.91	0.95	0.95	0.95	0.95	0.26
2000	0.01	0.10	0.57	0.89	0.93	0.93	0.93	0.93	0.24
2001	0.01	0.06	0.36	0.57	0.59	0.59	0.59	0.59	0.16
2002	0.00	0.04	0.21	0.33	0.34	0.34	0.34	0.34	0.10
2003	0.01	0.06	0.36	0.56	0.58	0.58	0.58	0.58	0.20
2004	0.01	0.07	0.40	0.62	0.65	0.65	0.65	0.65	0.20
2005	0.00	0.02	0.11	0.16	0.17	0.17	0.17	0.17	0.04
2006	0.00	0.05	0.29	0.44	0.46	0.47	0.47	0.47	0.11
2007	0.00	0.02	0.09	0.15	0.15	0.15	0.15	0.15	0.04
2008	0.00	0.01	0.08	0.12	0.12	0.12	0.12	0.12	0.04
2009	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00
2010	0.00	0.00	0.01	0.02	0.02	0.02	0.02	0.02	0.01
2011	0.00	0.01	0.05	0.08	0.08	0.08	0.08	0.08	0.03
2012	0.00	0.01	0.05	0.08	0.08	0.08	0.08	0.08	0.03
2013	0.00	0.00	0.02	0.03	0.03	0.03	0.03	0.03	0.02

Table 15: Limit reference point estimates for the Louisiana striped mullet stock. Spawning stock units are eggs x 10^{12}. Fishing mortality units are yr^{-1}.

Reference Points		
Parameter	Derivation	Value
SPR_{limit}	RS 56:333	30%
$F_{30\%SPR}$	Equation 38 and SPR_{limit}	0.15
$SS_{30\%SPR}$	Equation 38 and SPR_{limit}	3.29

Table 16: Sensitivity analysis table. Current estimates are geometric means of 2011-2013 estimates. Yield units are pounds ($x10^3$), fishing mortality units are yr^{-1}, and spawning stock units are eggs x 10^{12}.

Model run	negLL	$Yield_{30\%SPR}$	$F_{30\%SPR}$	$SS_{30\%SPR}$	$F_{current}/F_{30\%SPR}$	$SS_{current}/SS_{30\%SPR}$
Base Model	1369.0	3,427	0.15	3.29	0.16	2.28
h=.9	1369.4	3,342	0.15	3.21	0.16	2.31
h=.8	1369.1	3,250	0.15	3.12	0.16	2.37
h=.7	1369.2	3,088	0.15	2.97	0.16	2.49
Yield lambda (x4)	1245.6	3,517	0.15	3.38	0.15	2.33
Survey lambda (x4)	1368.9	3,748	0.15	3.60	0.14	2.72

11. Figures

Figure 1: Reported commercial striped mullet *Mugil cephalus* landings (pounds x 10^3) of the Gulf of Mexico derived from NMFS statistical records and the LDWF trip ticket program.

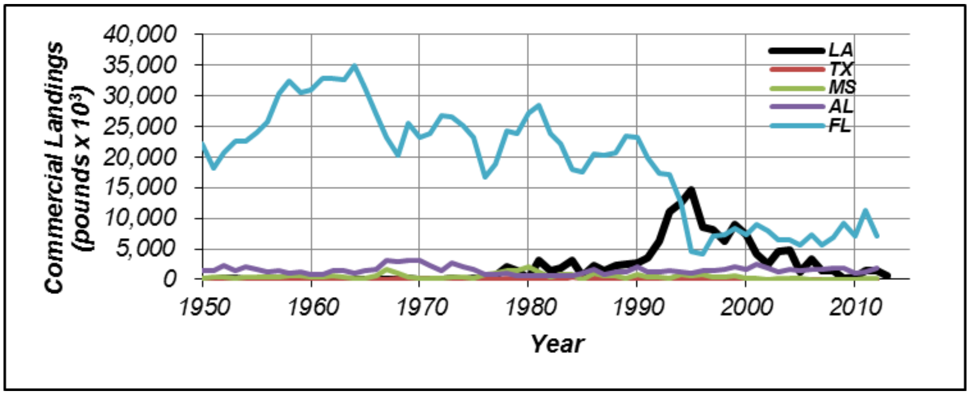


Figure 2: Estimated recreational striped mullet *Mugil cephalus* landings (pounds x 10^3) of the Gulf of Mexico derived from MRFSS/MRIP. Note: Texas does not participate in the MRFSS/MRIP survey.

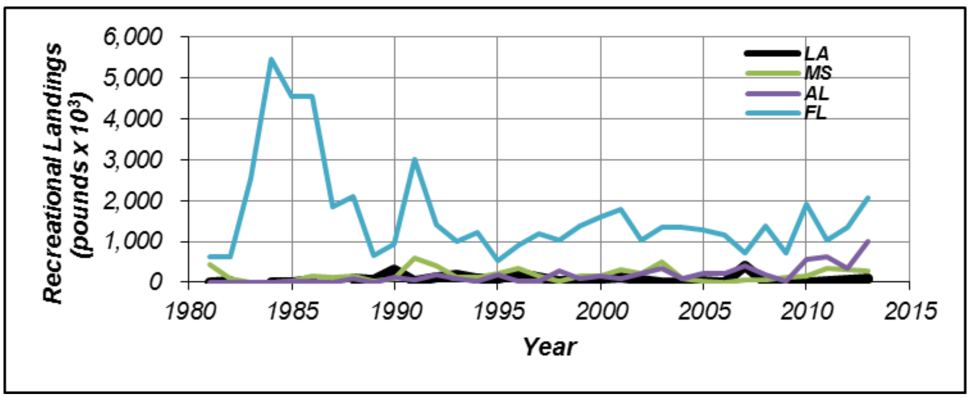


Figure 3: Standardized index of abundance, nominal catch-per-unit-effort, and 95% confidence intervals of the standardized index derived from the LDWF marine gillnet survey. Each time-series has been normalized to its individual long-term mean for comparison.

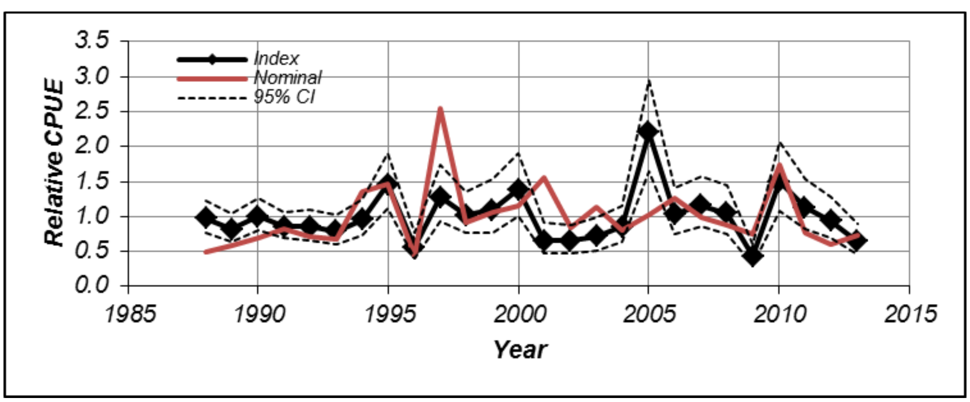


Figure 4: Observed and ASAP base model estimated commercial yield (females only; top) and standardized residuals (bottom).

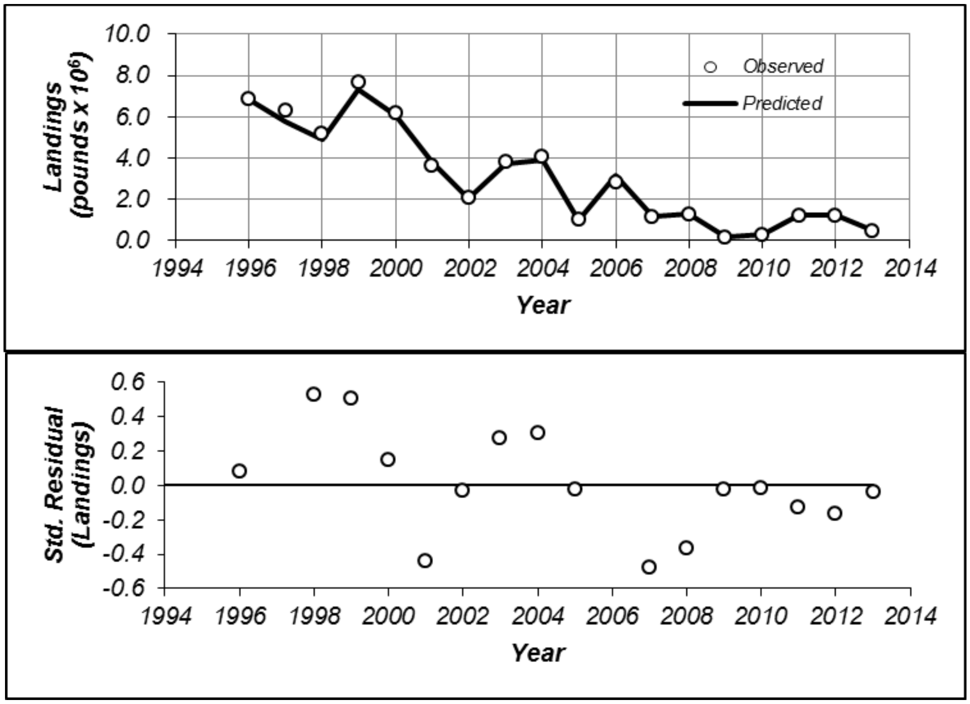


Figure 5: Observed and ASAP base model estimated fishery-independent CPUE (females only, top) and standardized residuals (bottom).

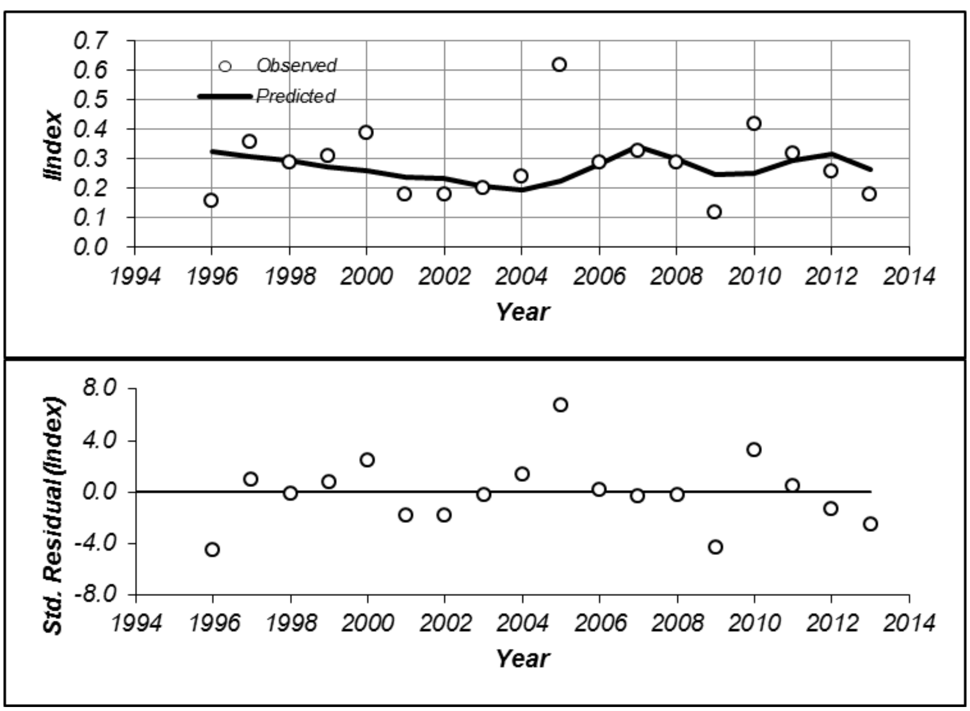


Figure 6: Annual input (open circles) and ASAP estimated (bold lines) commercial harvest age compositions.

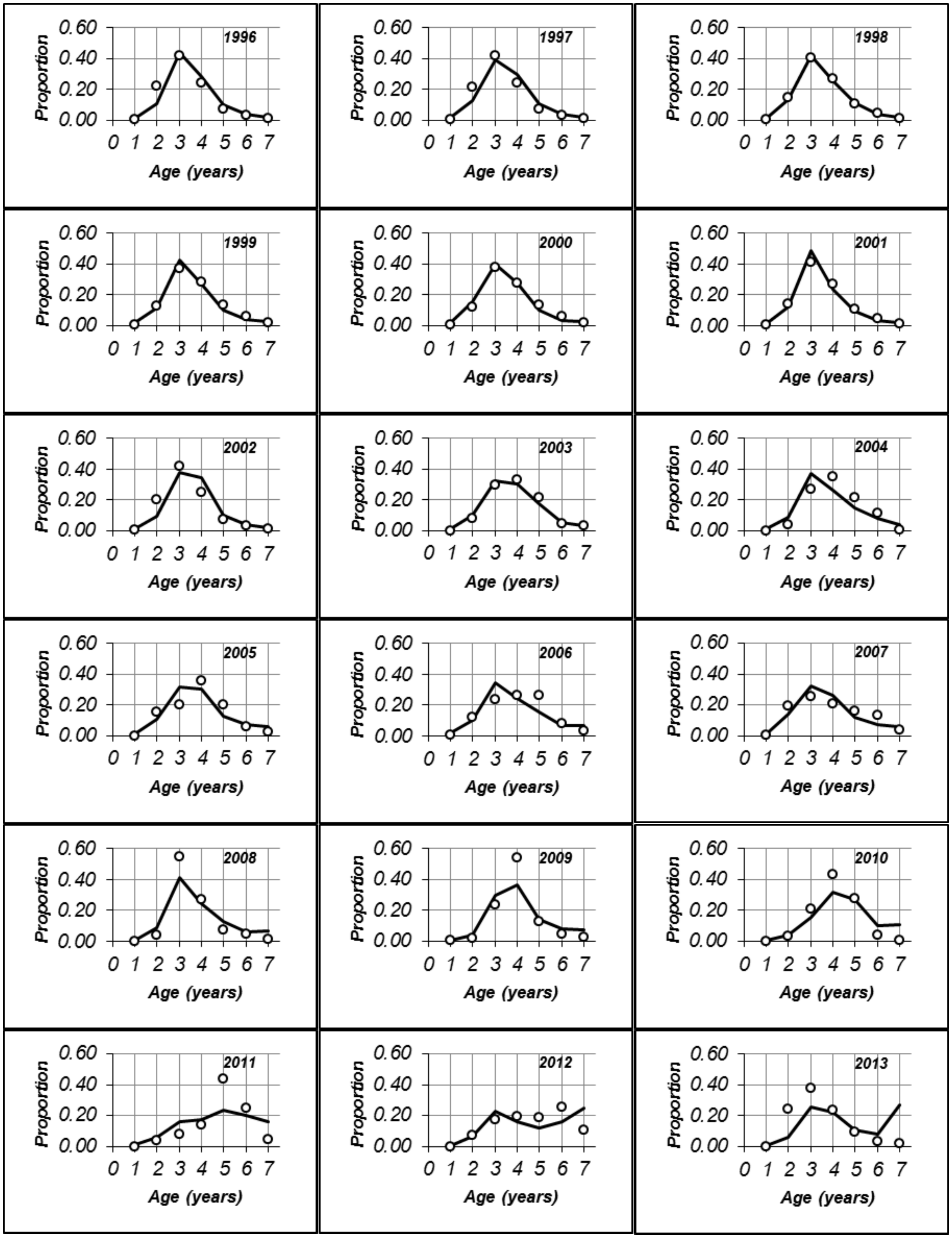


Figure 7: Annual input (open circles) and ASAP estimated (bold lines) survey age compositions.

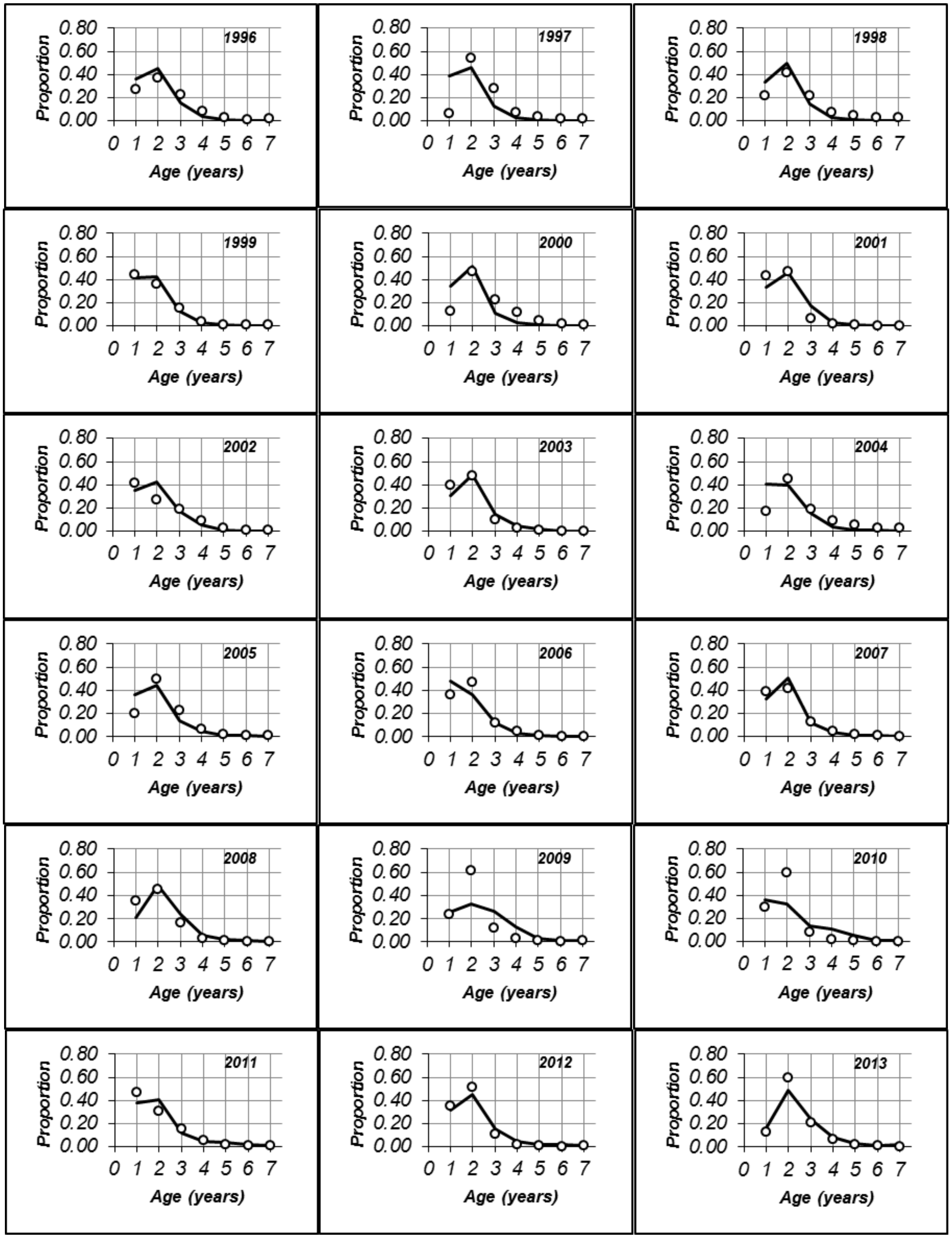


Figure 8: ASAP base model estimated fleet and survey selectivities (females only; ages 1-7+).

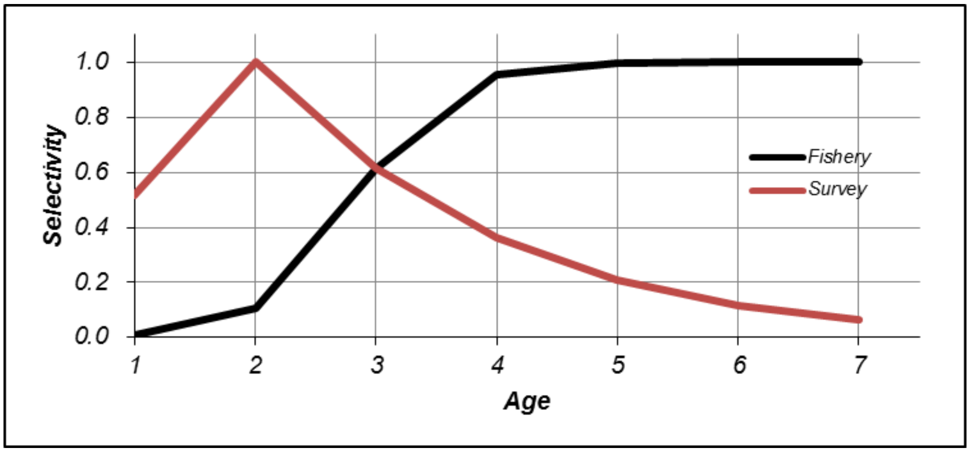


Figure 9: ASAP base model estimated recruitment (age-1 females). Dashed lines represent ±1 asymptotic standard errors.

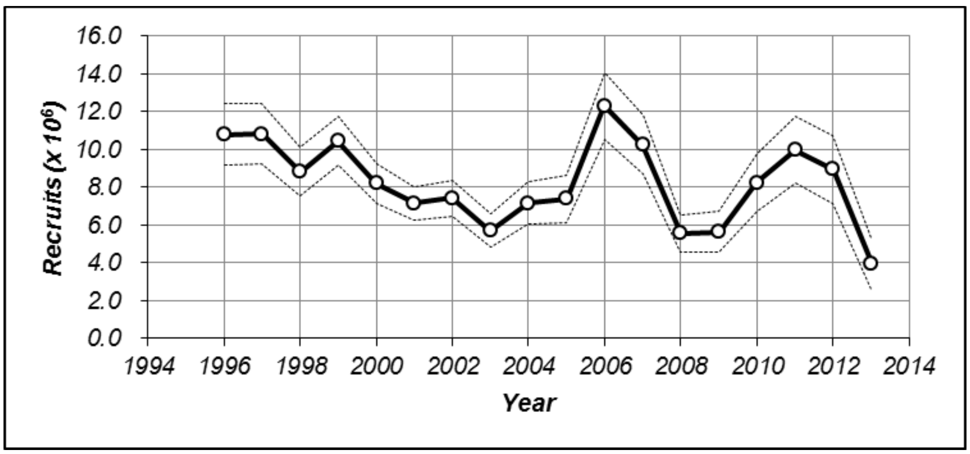


Figure 10: ASAP base model estimated egg production (MCMC median). Dashed lines represent 95% MCMC derived confidence intervals.

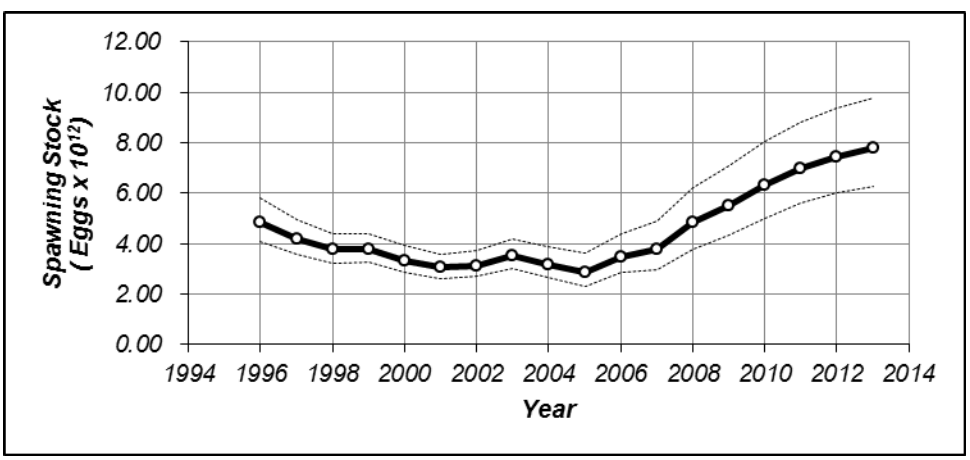


Figure 11: ASAP base model estimated average fishing mortality (MCMC median). Dashed lines represent 95% MCMC derived confidence intervals.

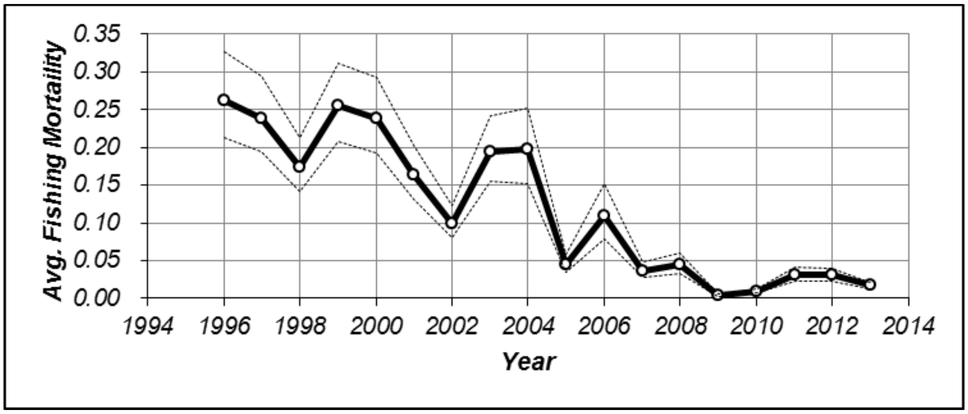


Figure 12: ASAP base model estimated age-1 recruits and spawning stock (total egg production). Arrows represent direction of the time-series. The yellow circle represents the most current data pair.

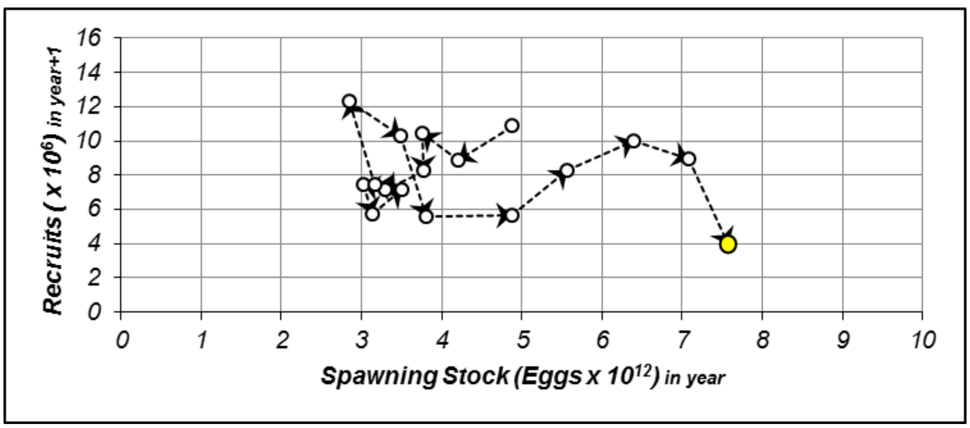


Figure 13: ASAP base model estimated age-1 recruits and spawning stock (open circles). Equilibrium recruitment is represented by the bold horizontal. The 2013 egg production estimate is represented by the yellow triangle. Equilibrium recruitment per spawning stock corresponding with the minimum and maximum spawning stock estimates are represented by the slopes of the dashed diagonals (min. spawning stock=26%SPR; max. spawning stock=72%SPR).

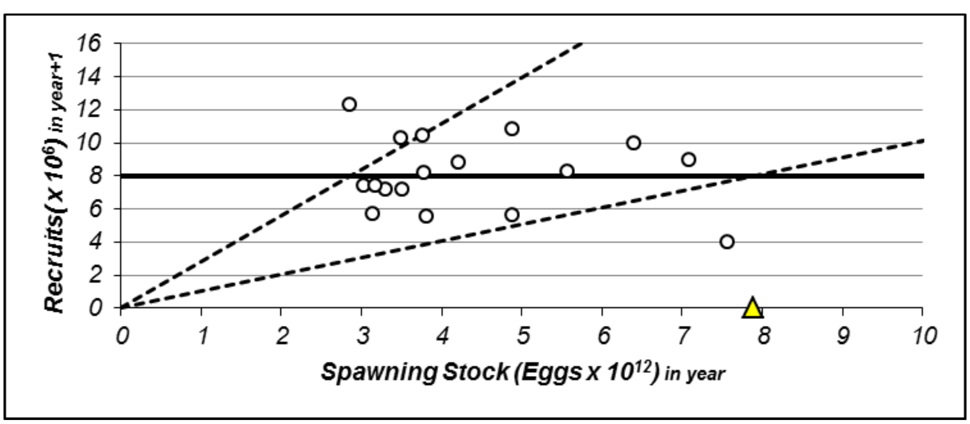


Figure 14: Retrospective analysis of ASAP base model. Top graphics depict estimated ratios of annual average fishing mortality to $F_{30\%}$ and spawning stock (egg production) to $SS_{30\%}$. Bottom graphic depicts estimated age-1 recruits.

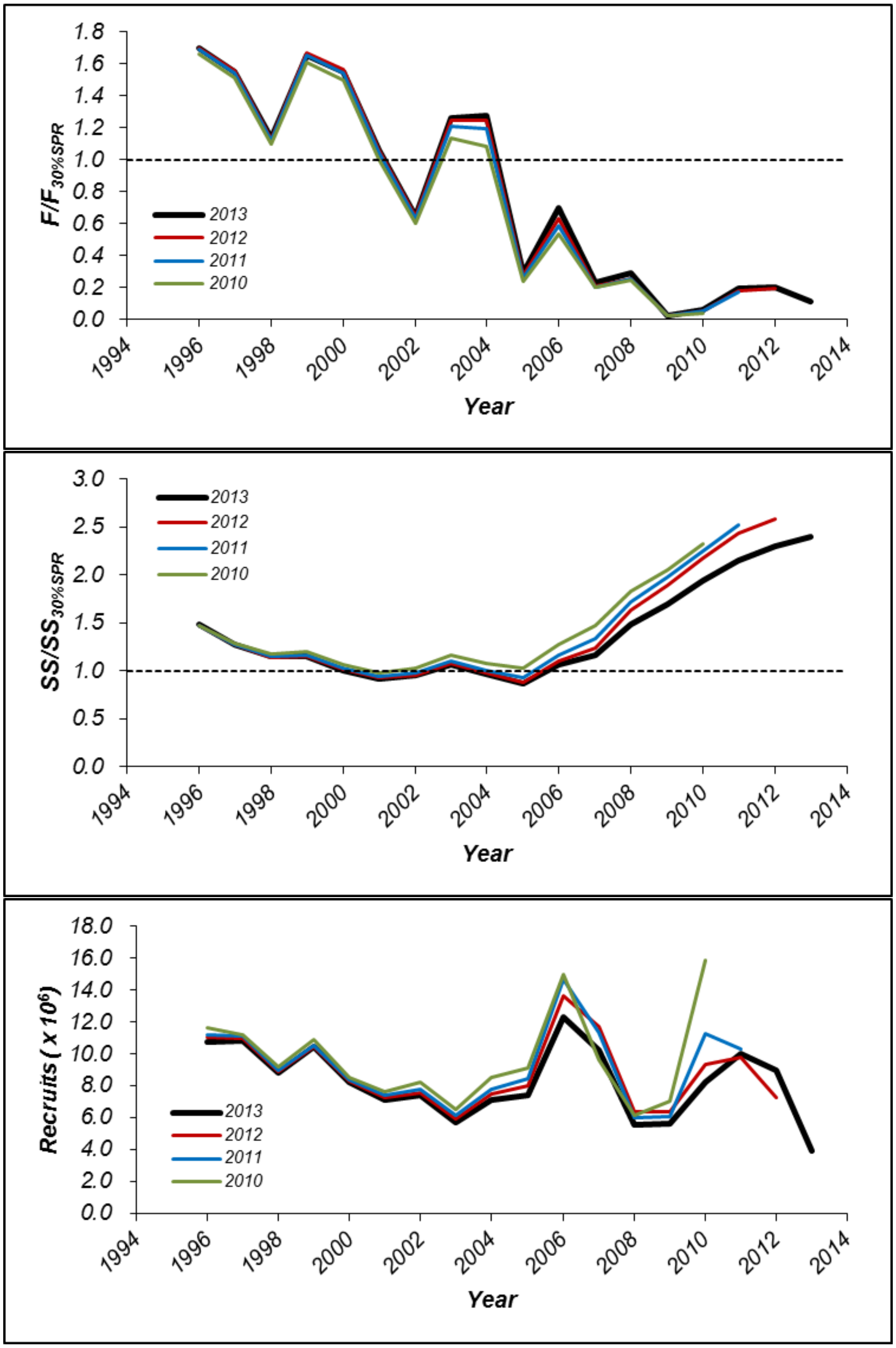


Figure 15: ASAP base model estimated ratios of annual average fishing mortality rates to $F_{30\%}$ and spawning stock size to $SS_{30\%}$. Arrows and dashed line represent direction of time-series (top graphic). The yellow circle represents current status (geometric mean 2011-2013 F and SS). Bottom graphic depicts results of 2000 MCMC runs relative to limit reference points and current status.